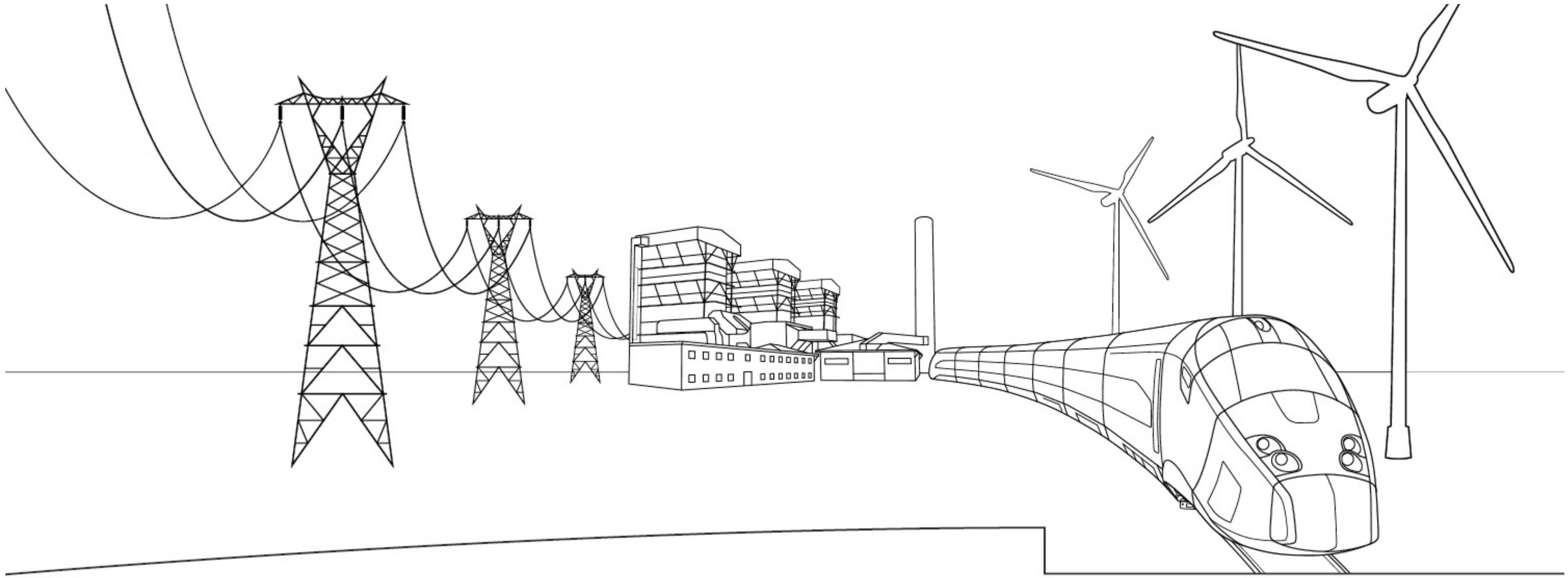

Implementation of Dynamic Thermal Ratings in the Operational Environment

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FERC Technical Conference:
Increasing Real-Time and Day-Ahead Market Efficiency through Improved Software
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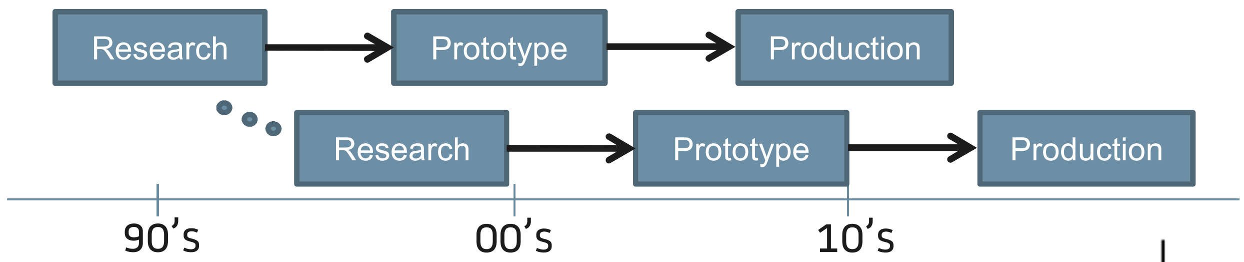
ALSTOM
Shaping the future

Outline

- Introduction
- Overview of Dynamic Line Rating (DLR) Technology
- Alstom's product solution for DLR
- Case Studies of DLR implementations
  - ERCOT
  - Peak Reliability (formerly WECC)
- Relationship with Adaptive Transmission Ratings
- Conclusions

Introduction

- The line rating represents the line current which corresponds to the maximum allowable conductor temperature for a particular line without clearance infringements or significant loss in conductor tensile strength.
- Transmission of electric power has traditionally been limited by conductor thermal capacity defined in terms of a *static line rating.*
- Transmission line ratings are determined using the conductor's heat balance and are dependent on the cooling effect of wind, warming due to line current, air temperature and solar heating.
- Static line ratings, based upon "near" worst-case weather and pre-load conditions, are still mostly used by the utility industry although dynamic line ratings technology has been advancing over the years.

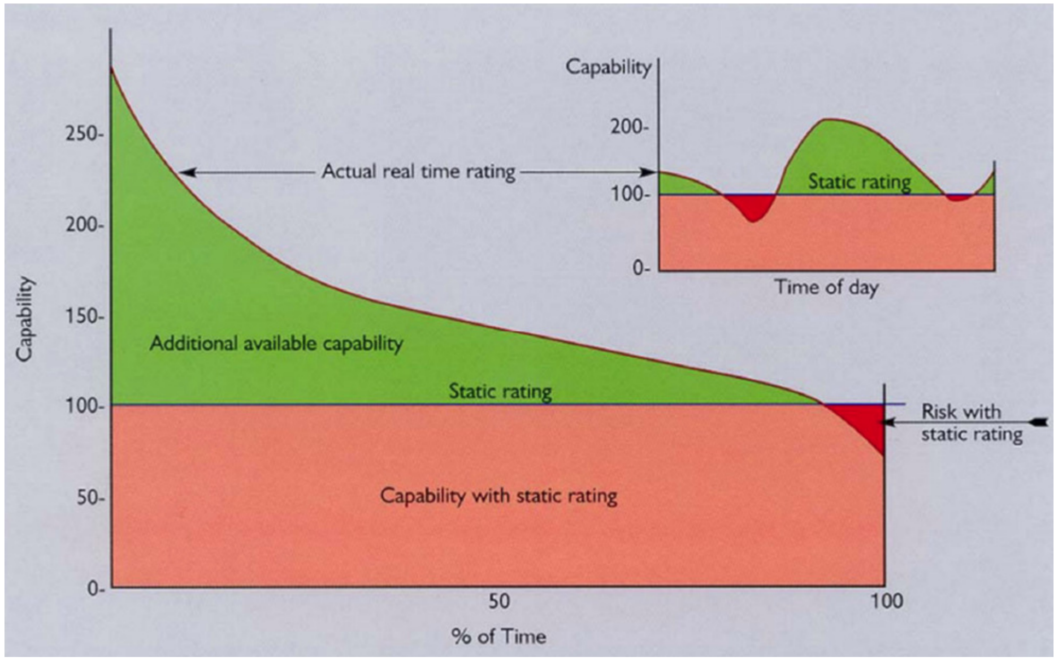


Introduction [Cont'd]

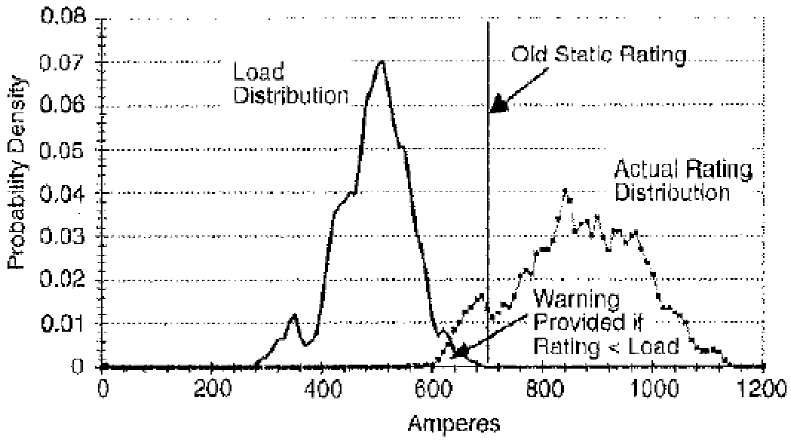
- In the last two decades, technologies and strategies have emerged to allow the real-time or pseudo-real-time measurement of transmission line characteristics and environmental conditions which enabled calculation of a real-time rating.
- As economic pressure builds to fully utilized the capacity of existing power equipment in both deregulated and regulated environments, dynamic line ratings can improve the efficiency of transmission operation by capturing unutilized line capacity while maintaining system reliability.
- Two key benefits of DLR over traditional static line ratings:
  1. Higher loading of equipment by developing more accurate thermal models.
  2. A better understanding of equipment thermal response is achieved resulting in higher reliability.

Dynamic Line Rating vs. Static Line Rating

- DLR enables significant amount of additional transmission capacity (Ampacity)
- DLR eliminates the risk in static rating



CAT-1 Transmission line monitoring system. The Valley Group. Available at http://www.nexans.be/eservice/Belgiumen/fileLibrary/Download_540145282/US/files/valley%20group_CAT-1.pdf



Dynamic thermal ratings realize circuit load limits
Douglass, D.A. ; Lawry, D.C. ; Edris, A.-A. ; Bascom, E.C.
Computer Applications in Power, IEEE
Volume: 13 , Issue: 1

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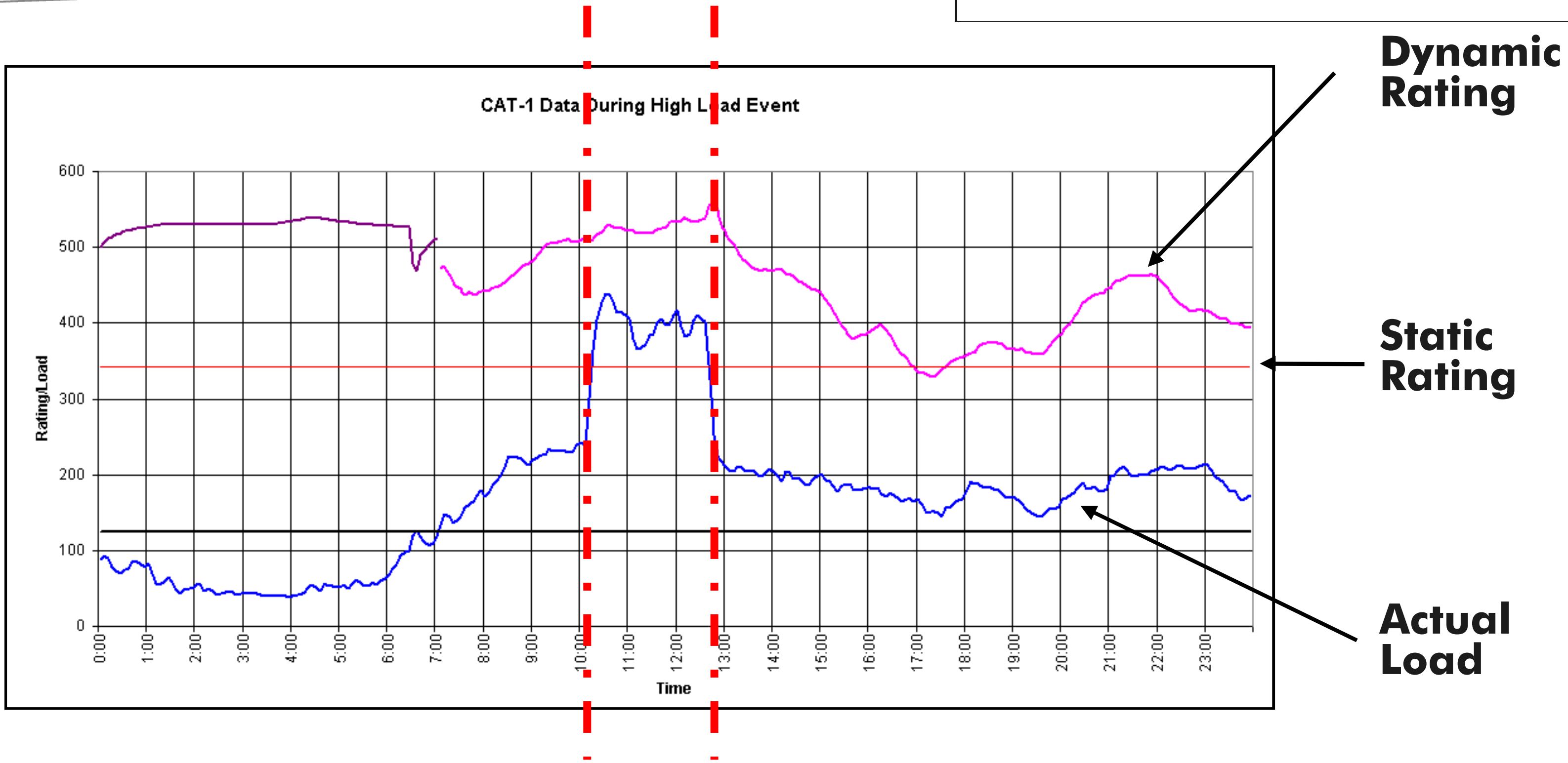
Impact On Transmission Grid Operations



- Line was operating within limits in accordance with operating standards.
- Without DLR, this event must be reported as a violation.
- The operator would have been forced to move the grid off its optimum dispatch.

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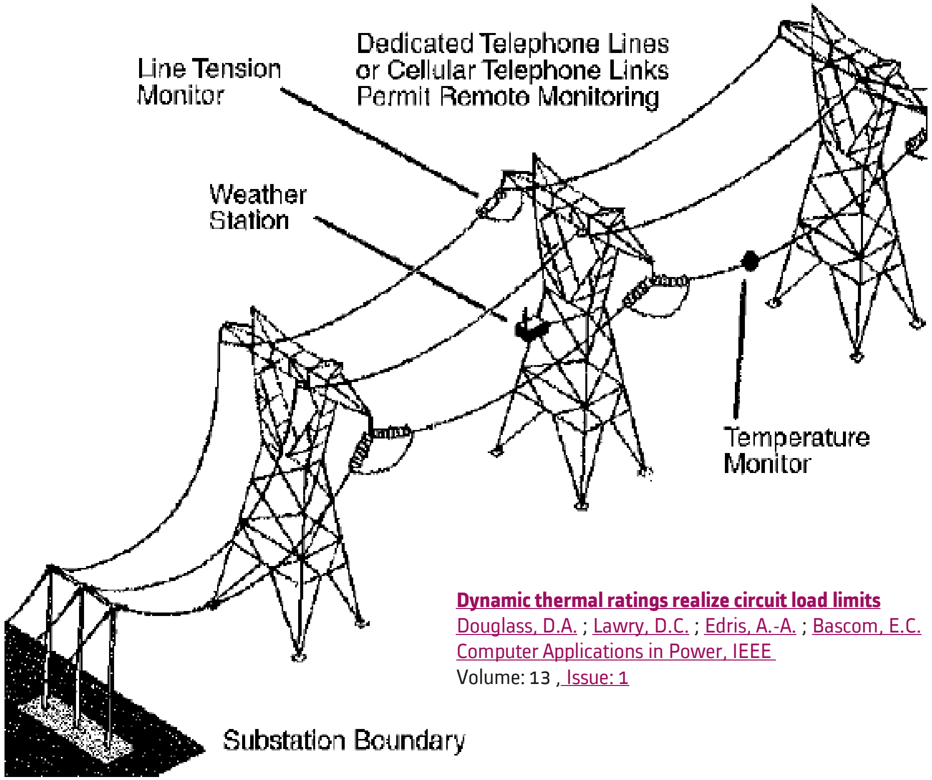
DLR Determination Methods

- Weather-based methods
  - Rely on monitoring e.g. ambient weather
  - Line temperature and sag are determined by theoretical models and calculations
- Temperature-based methods
  - Based on direct conductor temperature measurements in combination with other measurements.
- Sag monitoring methods
  - Measuring some characteristic of the line (e.g. tension) to determine the sag



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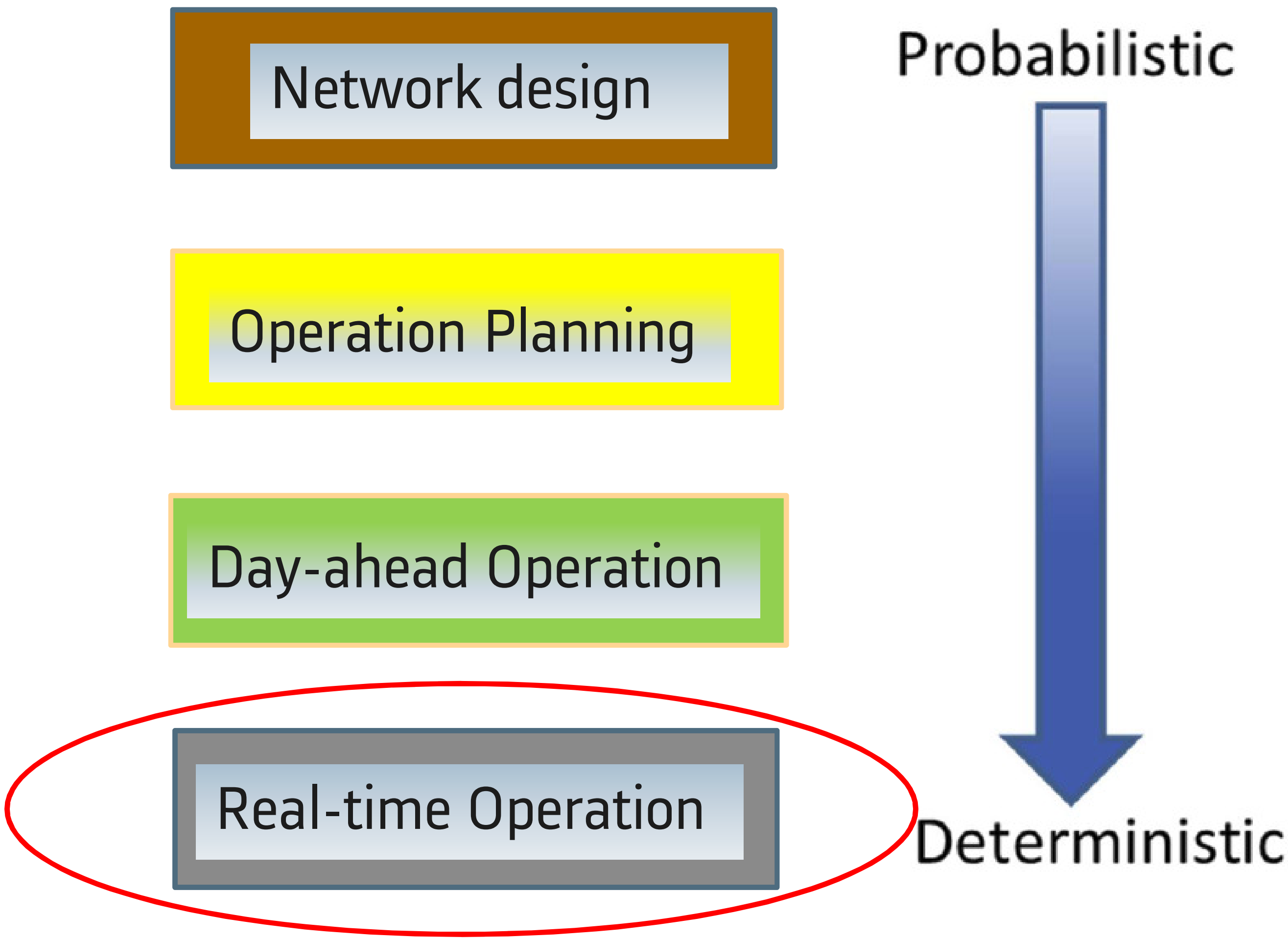
Dynamic Line Rating Approaches



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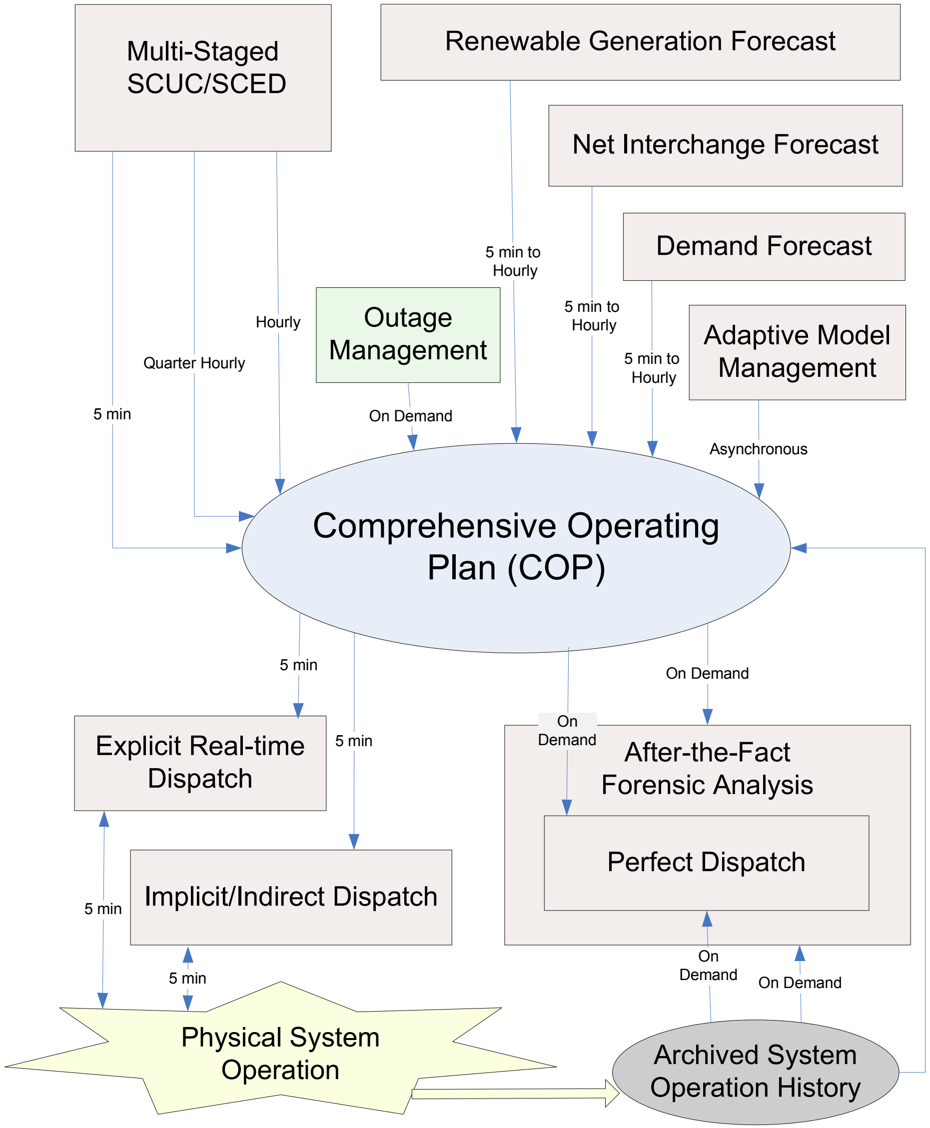
Alstom's Smart Dispatch Solution Overview



- Multi-stage SCUC/SCED
- Outage management
- After-the-fact forensic analysis (perfect dispatch)
- Renewable generation forecasting
- Net interchange forecasting
- Demand forecasting
- Adaptive Model Management
  - Adaptive generator modeling
  - **Adaptive constraint modeling**

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Challenges to Be Addressed by Product Solution

- Using static limits on transmission branches lower than true capability imposes congestion costs and market inefficiency.
- Using static limits on transmission branches higher than true capability poses reliability challenges.
- Static limits do not reflect ambient conditions (weakest link due to switching, ambient temperature, wind speed, sag, etc.)
- Need a centralized approach to limit management.
- Manual update in SCADA and RTNET (real-time network application) is time consuming and takes the focus away from operations.

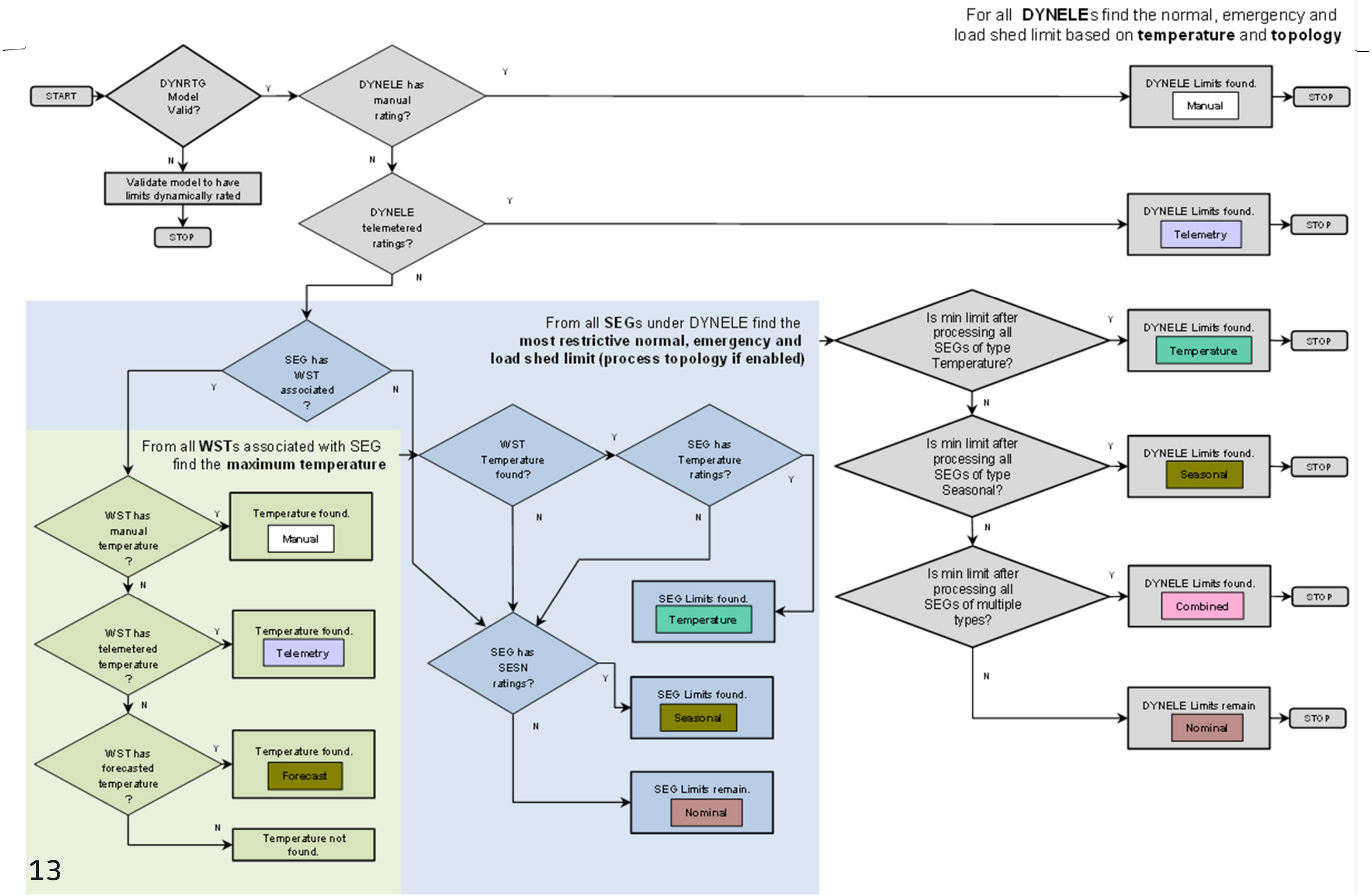
Salient Features of Product Solution (e-terra 3.0)

- Limits telemetered through SCADA
- Write dynamic rating limits to SCADA
- Compute ratings in real-time taking into account variables such as ambient temperature, switching / topology
  - Temperature based ratings computed using a temperature dependency model e.g. a static lookup table, polynomial function etc. Temperature input to real time application can be telemetered, manual entry, or forecast.
  - Topology processing triggered by QKNET to determine weakest link in series with each branch
- Dynamic ratings retrieved by RTNET and downstream applications for violation monitoring using the Dynamic Ratings API

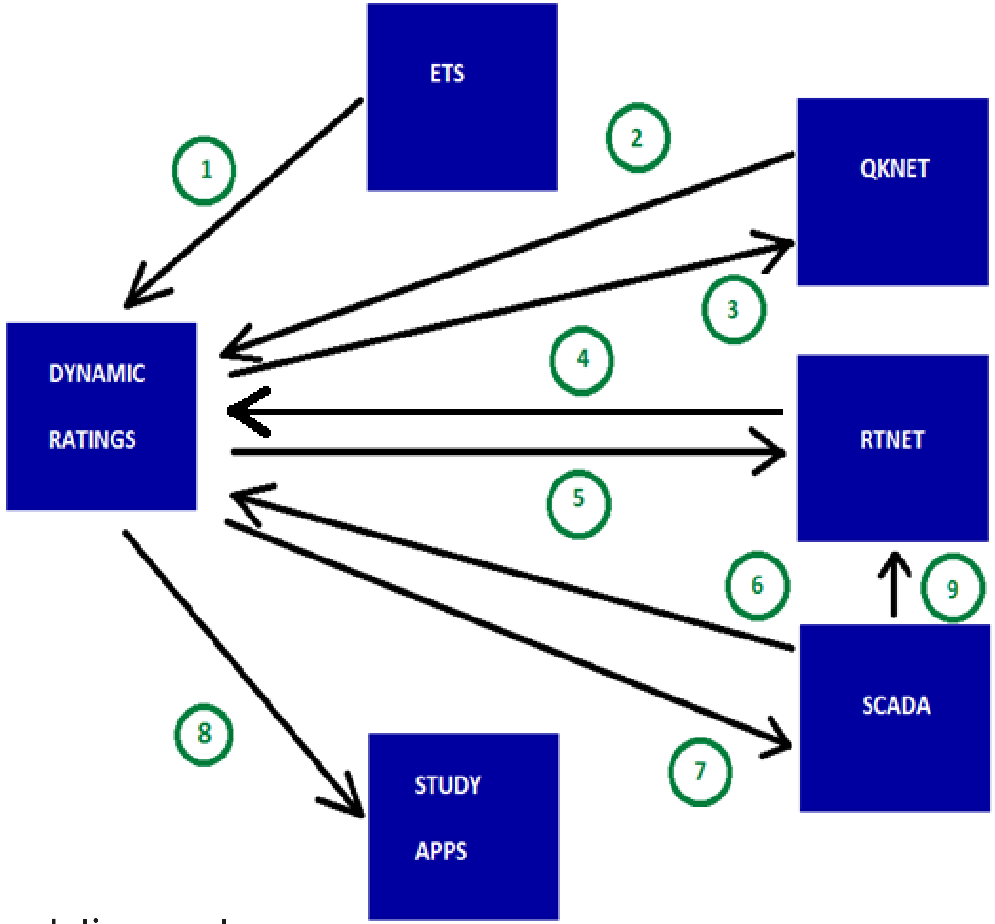
Salient Features of Product Solution [Cont’d]

- Compute ratings within study applications for look-ahead time frames in the future using forecasted temperature data.
- Traditional seasonal ratings supported.
- Alarming based on computed ratings.
- Simulation mode to compute ratings for a given temperature input without putting the ratings online.
- Manual overrides of ratings in a centralised application.
- Bring the model data online without operation interruption
- User Interface (iGrid display)

Functional Flow



Data Flow



DATA FLOW FOR DYNAMIC RATINGS (DR)

1 - ETS model input to DR

2 - QKNET topology for DR topology dependent limits

3 - Dynamic Ratings to QKNET via API

4 - RTNET violation for DR deration

5 - Dynamic Ratings to RTNET via API

6 - SCADA temperature telemetry to DR

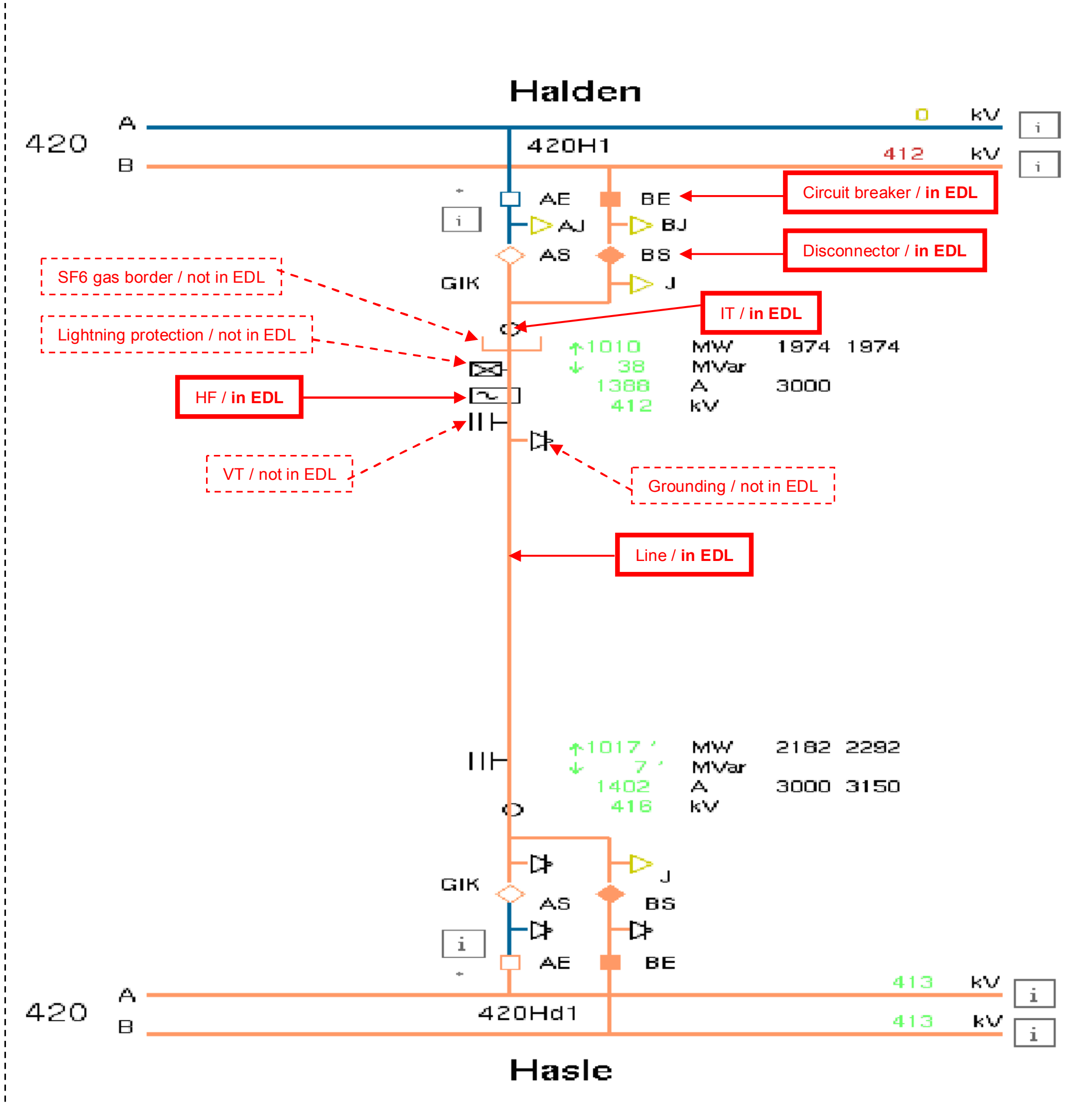
7 - DR computed limits (amp/MVA/MW) to SCADA

8 - Computed Ratings to Study Apps (STNET/SMTNET). Ability to compute ratings within Study Apps using forecasted temperatures.

9 - Limit copy from SCADA to RTNET

ETS – modeling tool
QKNET – Operator's UI for network
RTNET – state estimator

Topology Dependency



- For each device, evaluate its temperature dependency model
- Fetch breaker statuses from QKNET, based on which to determine the number of parallel paths at each branch terminal
- Terminal limit = most restrictive breaker limit * number of parallel paths
- Element limit = most restrictive component limit

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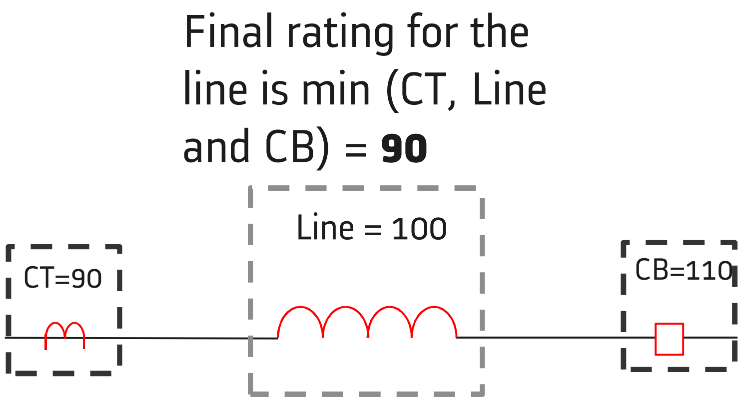
Dynamic Rating (DYNRTG) Introduction

- Calculates limits of individual network components based on ambient temperature and individual component restrictions on branches
- Example to compute dynamic rating for a line segment.



- Final dynamic rating for the line is calculated based of the most restrictive component limit making up the branch.

Dynamic Rating (DYNRTG) Introduction

- Supports multiple sources of limits for each element, such as manual entry, telemetered, temperature based, seasonal, and nominal ratings.
- If multiple sources are available, the limits are prioritized as manual -> telemetered -> temperature -> seasonal -> nominal

Case Study 1:
ERCOT's Implementation of DLR (DRA)

- Reliability Coordinator for Western Interconnection
- Formed as reliability council in 1970 and became an independent system operator in 1996.
- 23 million customers
- 41,500 miles of transmission lines
- 550 generators and 85% of electric load of the state of Texas with a peak of 68 GW.
- 20,000 square miles (75% of the land area of Texas)

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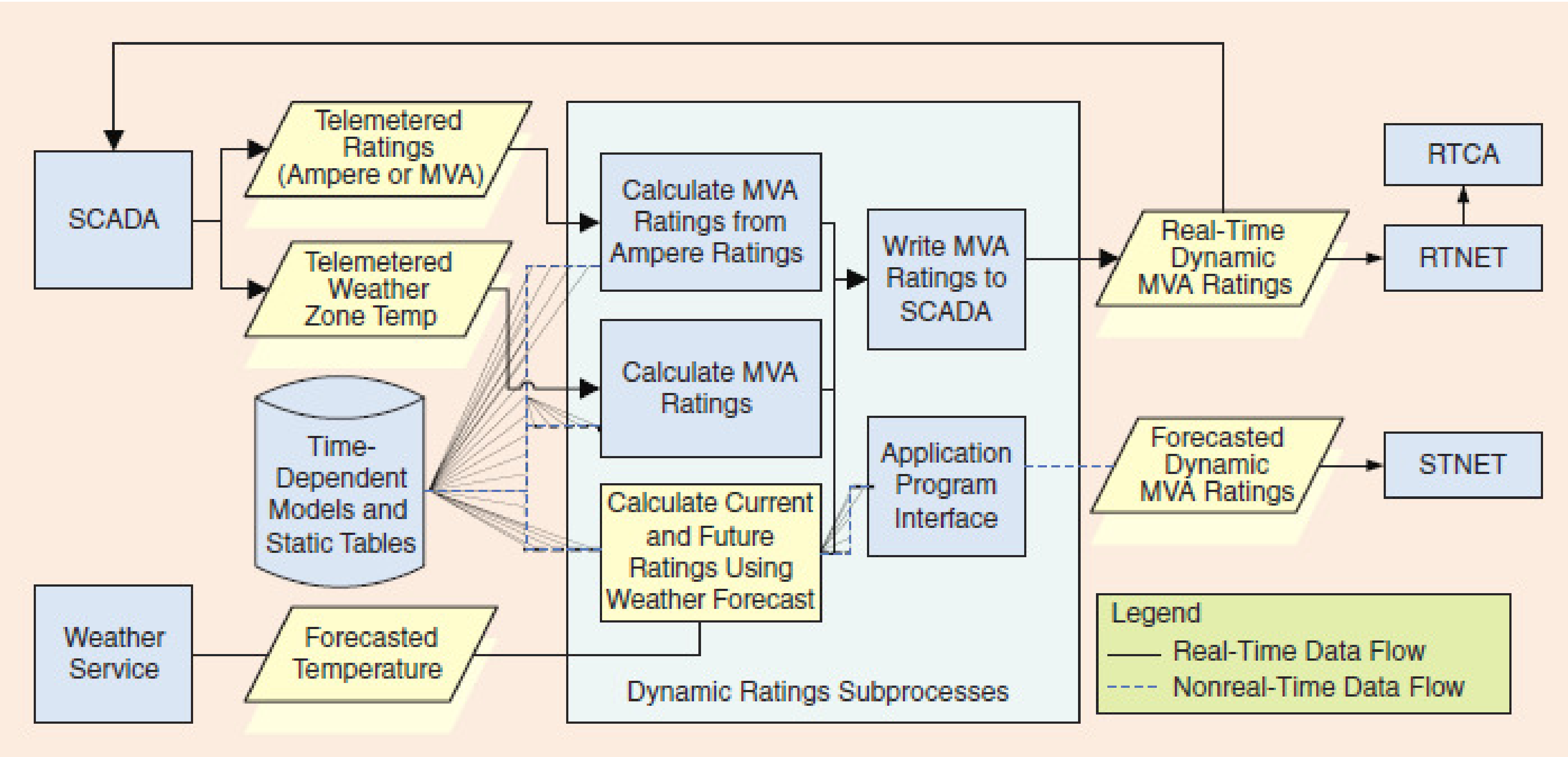
Project Background

- Deregulation has raised interest in the thermal capability of conductors for maximizing power transfer capacity from one point of transmission circuit to another.
- Transmission Service Providers (TSP) recognize the limitations of the conservative fixed rating and potential benefits of using dynamic thermal ratings.
- The primary purpose of the Dynamic Rating Application (DRA) is to improve the economic efficiency of the market.
- First ISO in the US (in 2007) to use real-time dynamic line ratings from TSPs to monitor and analyze system operations.

Functional Design

- DRA has two set of subprocesses
  - Real-time subprocesses
  - Non-real-time subprocesses
- Real-time Subprocesses
  - Receive data from TSPs via telemetry to calculate DLRs
  - Receive current weather-zone temperature from a designated weather service provider.
  - Once DLRs are calculated, they are written to SCADA.
  - From SCADA, DLRs are fed to downstream EMS and market applications including SFT and SCUC/SCED.
- Non-real-time Subprocesses
  - DRA provides forecasted rating using the forecast temperature from an external weather service and static table.
  - Forecast ratings are available via APIs to all look-ahead security analysis (e.g. STNET).

DRA Functional Relationship w/ other EMS Applications

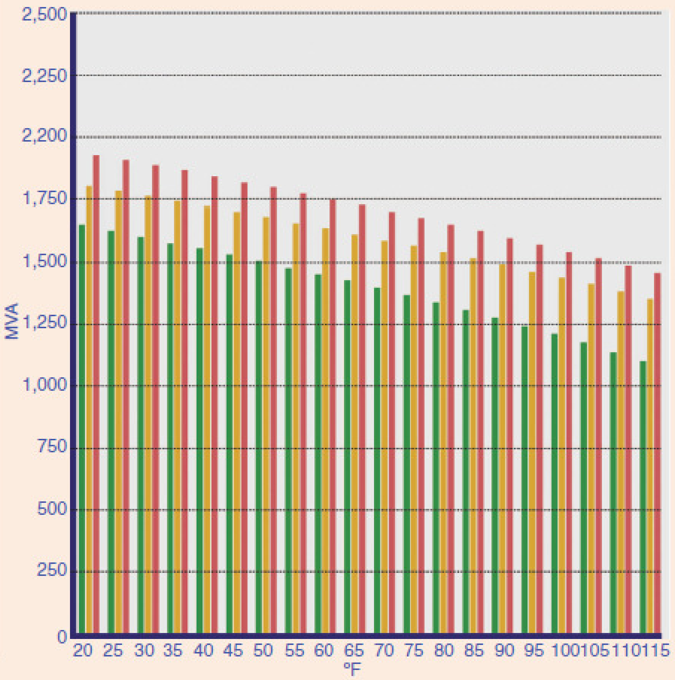


High-wire act
Kyeon Hur ; Boddeti, M. ; Sarma, N.D.R. ; Dumas, J. ;Adams, J. ; Soon-Kin Chai
Power and Energy Magazine, IEEE
Volume: 8 , Issue: 1

Benefits of DLR

Element	Seg ID	Valid	From ST	To ST	Nominal Ratings			TDSP	Adder	Weather Station	Done
XXX3	B	✓	ABOR	ABOV	1,178.0	1,412.0	1,509.0	DEF	0.0	SOUTH_C	

Temp (°F)	Ratings		
	Normal	Emergency	15 min
20	1,646.0	1,799.0	1,925.0
25	1,623.0	1,780.0	1,904.0
30	1,599.0	1,759.0	1,882.0
35	1,575.0	1,739.0	1,861.0
40	1,551.0	1,719.0	1,838.0
45	1,526.0	1,697.0	1,815.0
50	1,501.0	1,676.0	1,793.0
55	1,475.0	1,654.0	1,769.0
60	1,448.0	1,631.0	1,745.0
65	1,421.0	1,609.0	1,721.0
70	1,392.0	1,585.0	1,696.0
75	1,364.0	1,561.0	1,672.0
80	1,334.0	1,537.0	1,647.0
85	1,304.0	1,512.0	1,621.0
90	1,273.0	1,487.0	1,593.0
95	1,239.0	1,460.0	1,567.0
100	1,206.0	1,434.0	1,539.0
105	1,171.0	1,407.0	1,511.0
110	1,135.0	1,379.0	1,482.0
115	1,098.0	1,350.0	1,453.0



A typical winter day

CSC \ Limits	Transfer Limit (Dynamic)	Transfer Limit (Nominal)	Difference in MW (% Improvement)
South-Houston	1,200	1,090	110 (10%)
South-North	800	350	450 (128%)
North-West	760	580	180 (30%)
West-North	780	700	80 (11%)
North-Houston	3,300	2,700	600 (22%)

A typical summer day

CSC \ Limits	Transfer Limit (Dynamic)	Transfer Limit (Nominal)	Difference in MW (% Improvement)
South-Houston	3,280	3,130	150 (5%)
South-North	1,170	1,090	80 (7%)
North-West	710	650	60 (9%)
West-North	840	770	70 (9%)
North-Houston	2,940	2,910	30 (1%)

Branch Violations \ Study Model	Winter Case (Modest Change)		Fall Case (Extreme Change)	
	Dynamic	Nominal	Dynamic	Nominal
Number of base case violations	0	1	0	2
Number of contingency violations	6	11	0	30
Redispatch (MW)	349	1,188	0	3,617

High-wire act
Kyeon Hur ; Boddeti, M. ; Sarma, N.D.R. ; Dumas, J. ;Adams, J. ; Soon-Kin Chai
Power and Energy Magazine, IEEE
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- Increase of transfer limits on average (10-30% improvement)
- Less base case and contingency violations
- Dispatch more economically (improve social welfare)

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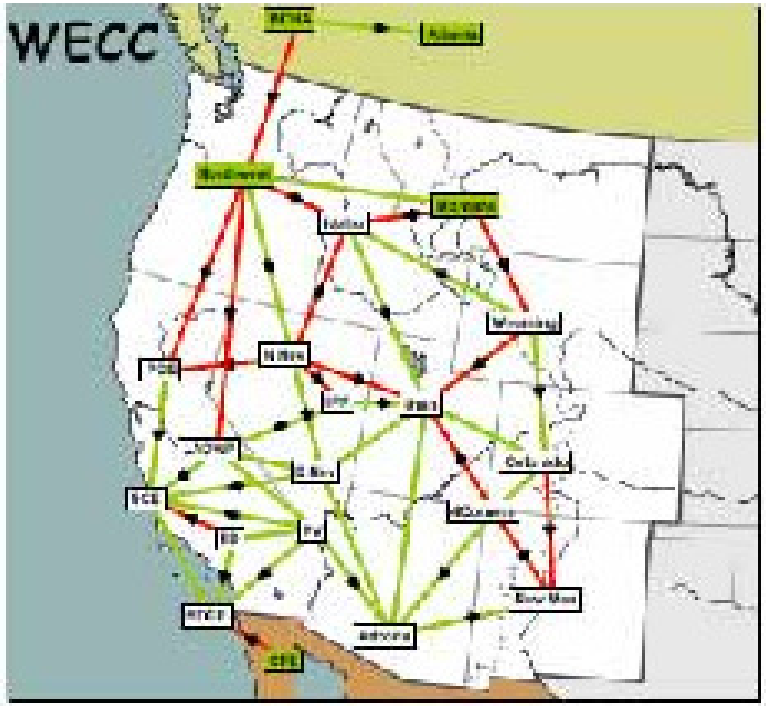
Case Study 2:
Peak Reliability (WECC)'s Implementation of DLR

- Reliability Coordinator for Western Interconnection
- Formed as independent regional Reliability Coordinator from WECC on 02/12/2014, based at Vancouver, WA and Loveland, CO
- 80 million customers
- 134,000 miles of transmission lines
- 1,800,000 square miles in 14 states / 3 countries



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Project Background

- With Balancing Authorities (BA) and Transmission Operator (TOP), Peak Reliability (formerly WECC RC) implemented the new System Operating Limits (SOLs) methodology for use in the Western Interconnection.
    - It raises the bar for BAs/TOPs to mitigate both real-time and post-contingency SOL exceedances by specific timer based requirements
    - A portion of BAs/TOPs already implemented dynamic rating limits in their EMS systems to reflect day-to-day variability in ambient weather conditions for optimal & secured transmission utilization
    - A couple of BAs/TOPs model and monitor transmission thermal limits in Amps unit other than the prevailing MVA unit
    - Introduction of dynamic rating application to embrace the new SOLs methodology

Dynamic Ratings Apps Overview

The dynamic rating (RTDYN) application aims to

- Support real-time and study/planning horizon dynamic rating
  - Use forecasted temperatures in F^0 when available in Study. Raw file interface for reading in temperature forecast.
- Currently account for branch thermal limits only
- Calculate MVA & Amps limits (only primary one enterable)
- Execute at 5 minute interval
- Real-time interface with SCADA only

Dynamic Ratings Apps Overview [Cont'd]

- Ability to use & process:
  - Temperature-dependent Ratings
  - Telemetry Ratings received via ICCP
  - Topology-dependent Ratings
  - MVA & Amps Ratings
    - Amps Ratings converted to MVA Ratings using State Estimator solved Bus KV (conservative based)
  - Seasonal Ratings (manual toggle for switching)
- Ability to accommodate multiple ratings types simultaneously (priority order-based)
- Production in March/April 2014.

What is Adaptive Transmission Rating?

- Post-contingency thermal transmission constraints are based on transient Emergency Ratings of lines and transformers:

$$\text{Post contingency flow} \leq \boxed{\text{Emergency Rate}}$$

- Emergency Rate is typically a static parameter and equals to Long-Term Emergency (LTE, 4 hours) or Short-Term Emergency (STE, 15 min) rate
- $STE \geq LTE$ → Which rate $Rate(time)$ to use?
- Adaptive Transmission Rate (ATR) concept intends to adaptively select Emergency ratings by accounting for the post-contingency dispatch and pre-contingency conductor loading

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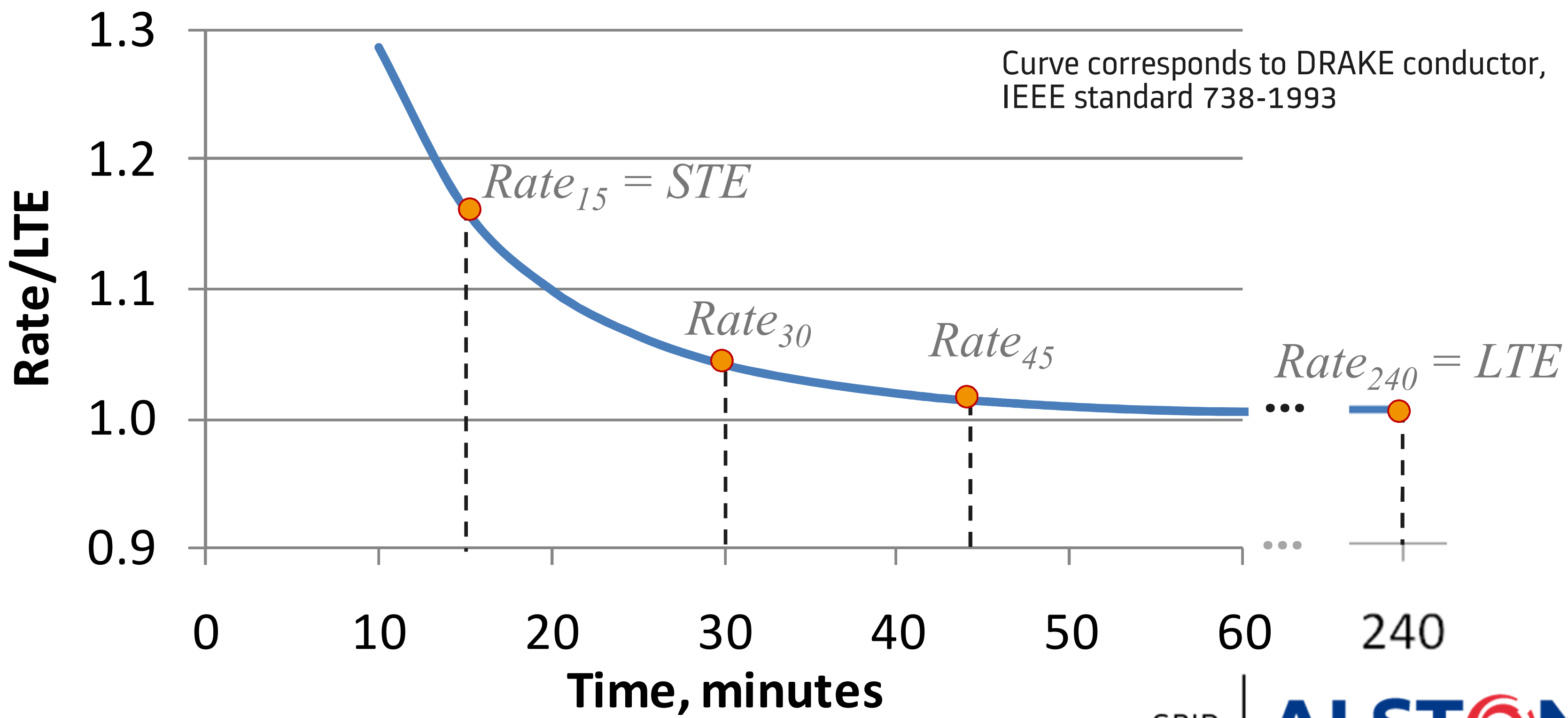
Rate(time) Characteristic

- *Rate(time)* is a physical characteristic and can be developed for each line by using the same methods as for calculation of *STE* and *LTE*



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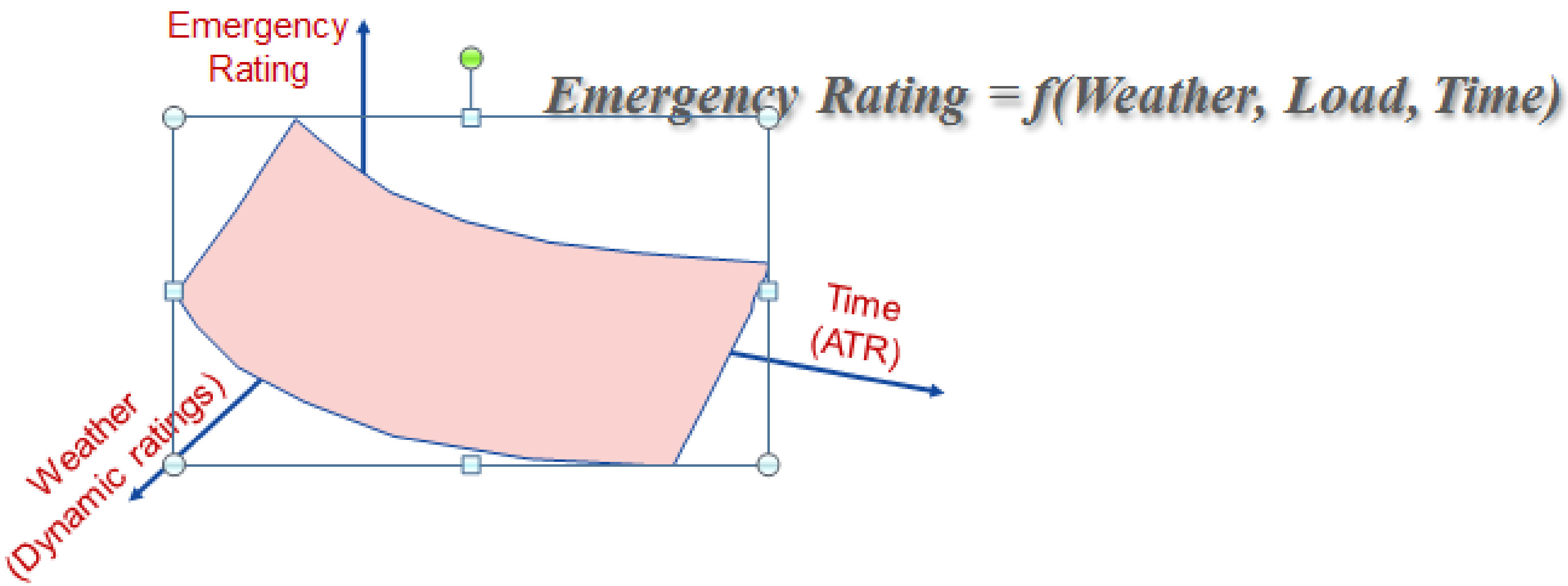
Adaptive Transmission Rating (ATR)

- ATR Objective: Safely increase the utilization of transfer capability of the power system by accounting for system’s post-contingency ramping capabilities including post-contingency corrective actions.

- The effect is achieved via estimation of adaptive maximal values of emergency ratings, which can be safely used for enforcing post-contingency transmission constraints in dispatch instead of traditionally used fixed emergency rates.

- ATR is different from but complementary to dynamic rating



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Conclusions

- The technology of Dynamic Line Rating (DLR) is reviewed.
- Alstom's product solution features for DLR calculation are described.
- Two case studies of DLR implementations are discussed.
- DLR can significantly improve the economic efficiency of both real-time and day-ahead markets by reflecting the change in ambient weather conditions to determine the ratings of key transmission elements.
- Adaptive Transmission Ratings (ATR) is different from but complementary to DLR.
- More advanced DLR determination methods are expected to be incorporated in future Alstom's product solutions.

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